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13. ABSTRACT *(Maximum 200 words)*

We summarize our second quarter progress and discuss third quarter plans for the development of an edge emitter based vacuum triode with performance goals of 10μA/μm emission current density at less than 250V and which can be modulated at 1 GHz for 1 hour. Design and layout of the emitter test mask was completed and fabrication of two process runs of edge emitter diodes were completed. These diode emitters utilize a comb emitter design where high resistivity TaN thin films act as current limiters to prevent edge burnout. Testing of these devices will start during the third quarter. Initial design work on the edge emitter triode was started and is described. Extensive finite element modeling (FEM) and analysis to aid in the triode design took place and is described. Significant process development also took place. Experimental studies of dielectrics such as sputtered SiO_2, Si_3N_4 and PECVD SiO_2 and Si_3N_4 were carried out to understand their leakage characteristics and, thus, understand their impact on emitter performance. A description of our vacuum test station is also given.

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R&D Status Report
RF Vacuum Microelectronics
Quarterly Progress Report #2
(1/1/1992 - 3/31/92)

Sponsored by:

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Effective Date of Contract: September 30, 1991

Contract Expiration Date: March 31, 1993 (Baseline)

Contract Amount: Baseline $1,315,650

Option: $ 772,532

Principal Investigator: Tayo Akinwande 612/887-4481

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Title of Work: **RF Vacuum Microelectronics**

I. Executive Summary

Program Objective: **Demonstrate an edge emitter based vacuum triode with emission current density of 10 μA/μm at less than 250 V which can be modulated at 1 GHz continuously for 1 hour.**

Key Achievements (this reporting period)

- Developed thin film TaN resistor with 10^1-$10^6\Omega$/square resistivity.
- Completed field emitter test mask incorporating comb emitters and current equalization structures.
- Completed first run of diode field emitters.
- Developed electromagnetic finite element model (FEM) of thin film edge emitter structure.
- Completed assembly of ultra-high vacuum test system with automated data acquisition.

II. Milestone Status

	Completion Date	
1. Field Emitter Development		
Test Structure Design Complete	12/91	1/92
Determine Workable Emitter Structure	3/92	3/92
Demonstrate Emission Current of 10 μA/μm	11/92	11/92
Deliver 10 Field Emitting Diodes	12/92	12/92
2. Process Development		
High Resistivity Thin Film Resistor	4/92	4/92
Complete Dielectric Studies	5/92	5/92
Mechanical and Electrical FEM Analysis	5/92	5/92
3. Triode Development		
-Triode Design Complete	4/92	5/92
-Demonstrate Reliable/Uniform Current Emission	7/92	8/92
-Demonstrate Modulated/Edge Emitter Triode	8/92	9/92
-Demonstrate 1 GHz Modulation of Triode	2/93	2/93
-Deliver 2 Triodes	3/93	3/93
4. Final Report (Baseline)	4/93	4/93

III. Technical Progress

Efforts during this reporting period focussed on the following:

- Completion of the two-terminal device (field emitter diode) mask set
- Initial fabrication runs of thin film emitter diodes
- Characterization of TaN thin films for use as current limiting resistors
- Characterization of thin film dielectrics (sputter and PECVD deposited SiO_2, Si_3N_4, etc.) for use as insulators in diode and triode structures
- Development of a finite element model (FEM) for an edge emitter triode to understand field strengths and behavior near the emitter tip, control electrodes and anode
- Initial design of an edge emitter triode structure.

Task 1. Field Emitter Development

We have completed the two-terminal device (field emitter diode) mask set. The mask set has a variety of devices that address the technical issues relating to the reliability of the emitter. Our design approach includes (i) use of thin film (~200Å) emitters, (ii) refractory metal comb structures to prevent burn-out, and (iii) current equalization with resistive elements to stabilize emission current. This also includes the use of layered emitter structures, heat treatment of the anode or the emitter with and without bias, and electropolishing of the emitters.

The first process fun of 12 wafers has been completed with this mask set. There are three splits of emitter thickness: 1) 200Å TiW, 2) 300Å TiW, and 3) 400Å TiW. Each split consists of three quartz wafers and a silicon wafer with 2.5 μm of silicon dioxide. Parametric testing of these wafers has started and device testing will begin in early April. A second process run of wafers has begun.

Task 2. Process Development

Much effort was expended this quarter on developing high quality TaN thin film resistors for use as current limiters in the edge emitter diode and triodes and on understanding the electrical properties of several dielectrics which have potential as insulators separating the emitter and control electrodes. Some discussion about the TaN resistors appears in the first quarterly report. We now feel we can reliably deposit TaN films with controlled resistivity between 10^1 and 10^6 Ω/square by varying nitrogen concentration. We see some degradation of resistivity of the TaN following sputter etching which we attribute to N removal from the surface. This Ta accumulation can be removed by an appropriate etch so the resultant resistivity remains predictable and controllable. TaN is being used in our first diode emitter fabrication runs.

A study of the dielectric films used in the VME structures was started to determine the quality of the films. Obviously there will be high electric fields present in the structures and the dielectric films must be of high quality with low leakage currents and high breakdown fields for proper device operation. The dielectric films used in the VME structures include both silicon nitride and silicon dioxide films deposited by sputter deposition and also by plasma enhanced chemical vapor deposition (PECVD). The following dielectric films were studied:

- Sputtered Silicon Nitride with high bias
- Sputtered Silicon Nitride with low bias
- PECVD Silicon Nitride
- Sputtered Silicon Dioxide
- PECVD Silicon Nitride.

Breakdown strengths of all the films were greater than $8x10^6$ V/cm. The leakage current in the silicon nitride films was high and increased with the applied field. The oxide films had much lower levels of leakage current and could provide the isolation needed in the structures. Annealing of the films provided some improvement in the silicon nitride films and some degradation of the oxide films.

For the diode and triode structures, the best dielectric isolation may be composite stacks of oxides and nitrides to maintain low leakage current and a high dielectric breakdown field between the active electrodes. We will be examining composite structures further in the next quarter.

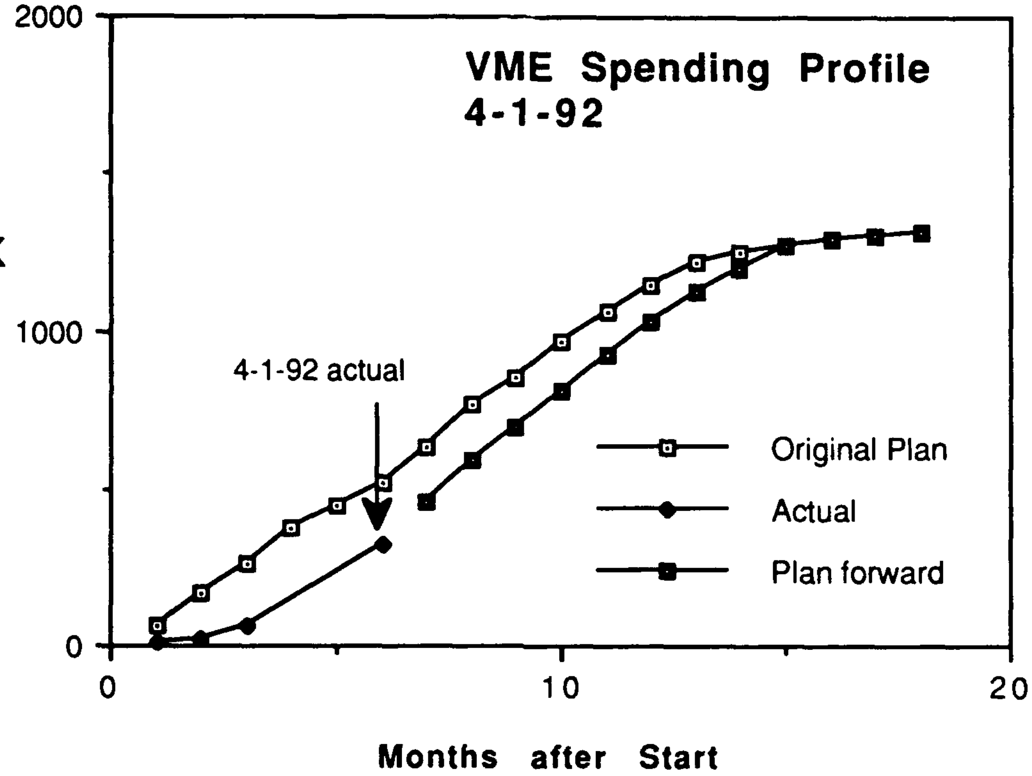
Task 3. Triode Development

Layout of the triode mask set has been initiated. Most of the triodes in this mask set have resistors in series with emitter fingers for current equalization. We are being guided in the design of the triodes by results from a finite element model (FEM) of the electromagnetic field behavior in the vicinity of the emitter, anode and control electrodes. A more extensive discussion of the results will be presented in the next quarterly. We expect the triode mask set to be ready for fabrication by mid-May.

Plans for next reporting period:

- Complete triode emitter design
- Continue FEM analysis of triode structure
- Test diode edge emitter from first two process runs
- Continue diode edge emitter fabrication runs
- Carry out emitter conditioning experiments to maximize current and eliminate burn-out
- Carry out atomic force microscopy of emitter materials to examine surface condition of the edge
- Carry out edge smoothing experiments.

IV. Fiscal Status



Expenditures this quarter	$263,556
Total expenditures to date	$ 323,633
Projected expenditures:	
4/92 - 6/92	$371K
7/92 - 9/92	$334K
10/92 -12/92	$240K
Total Projected Cost for FY92	$1,030K
Total Projected Cost for Baseline Program	$1,315,650

V. Problem Areas

- We continue to be somewhat behind spend plan and technical plan through the 2nd quarter of the program. This is due to the late start of the University of Minnesota contract and also is due to delays in getting our vacuum test station up and running. These issues have been taken care of and we expect to make up much of the difference between actual and plan over the next two quarters. We expect to be back on plan, both spending and technical, in the first quarter of FY93.
- The University of Minnesota subcontract to look at vacuum encapsulation techniques for vacuum triode isolation has been accepted by our ACO and has been negotiated with the U of M in March. Work should commence immediately.

VI. Visits and Technical Presentations

- SSDC hosted a final program review for the FEATRON Program on February 7. Larry Fletcher (COTR) and Henry Gray (NRL) were the government attendees. A final report has been written and is available from L. Fletcher. A copy was delivered to Bert Hui.
- Tayo Akinwande and Norm Foss attended the DARPA VME semi-annual review on March 20 in Washington, DC.
- We are preparing a paper for submission to International VME Conference scheduled for this summer in Vienna.